"Using satellite observations and models to understand processes in the chemistry-climate system"

Presented by: Apostolos Voulgarakis

GISS Lunch Seminar, 11th of May 2011

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y. 10025

CENTER FOR CLIMATE SYSTEMS RESEARCH
THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY

My interests:

- *Climate forcing-response relationships.*

i.e. how forcing agents from different geographical regions affect climate and our understanding of regional climate sensitivity (of temperature and precipitation).

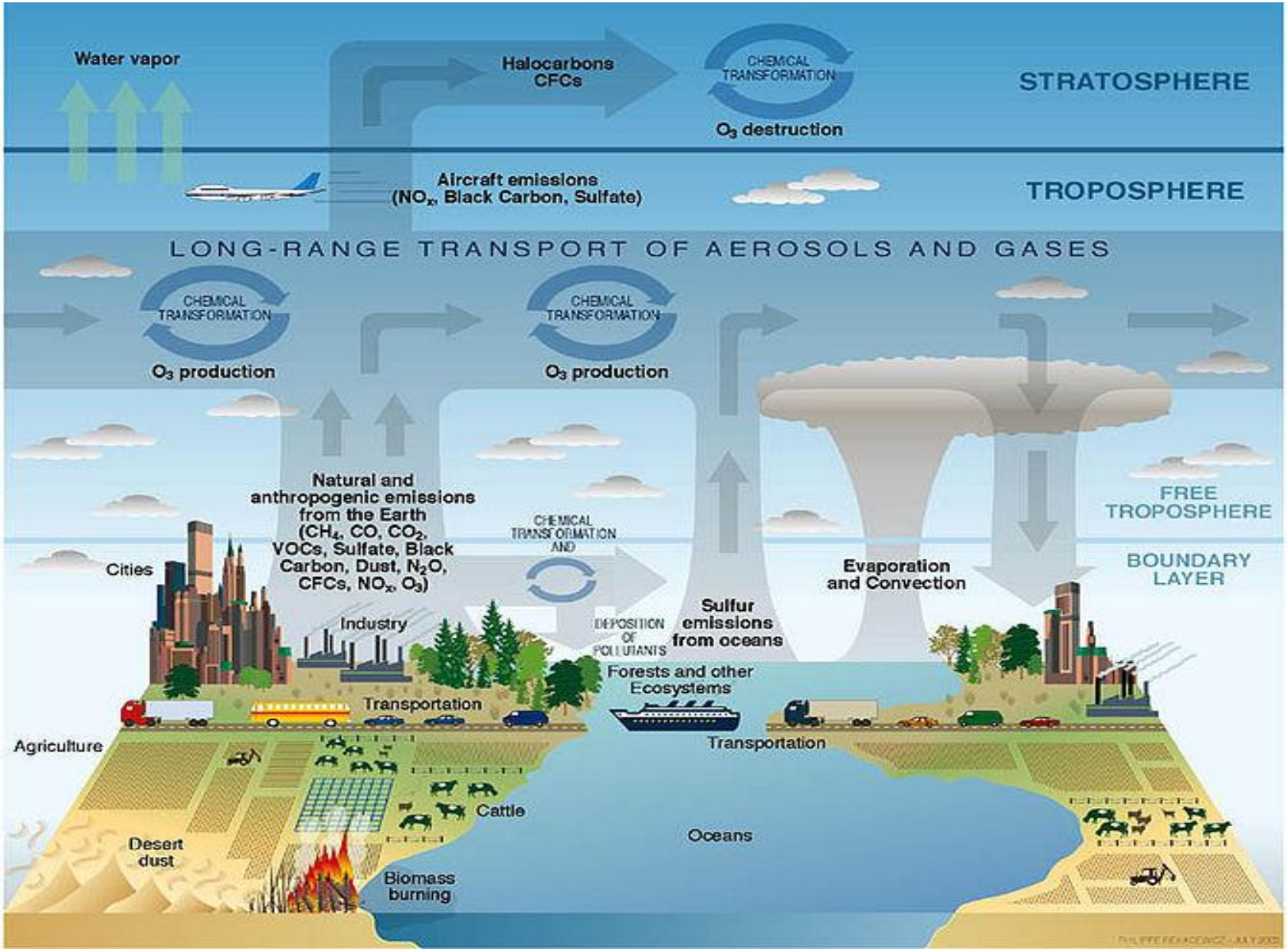
(For more, see: Voulgarakis, A. and Shindell, D. T. [2010a], *Journal of Climate*.)

- ***Variability of tropospheric composition and how it interacts with climate (chemistry-climate interactions).***

i.e. Examining how ozone (O_3), carbon monoxide (CO), hydroxyl radical (OH), nitrogen oxides (NO_x) etc are affected by emissions, climate variability and climate change, with the use of global models and observations.

(For more, see: Voulgarakis et al. [2009a, 2009b, 2009c, 2010b, 2011a, 2011b].)

Atmospheric chemistry related processes:



Source: US Climate Change Science Program.

Recent advances

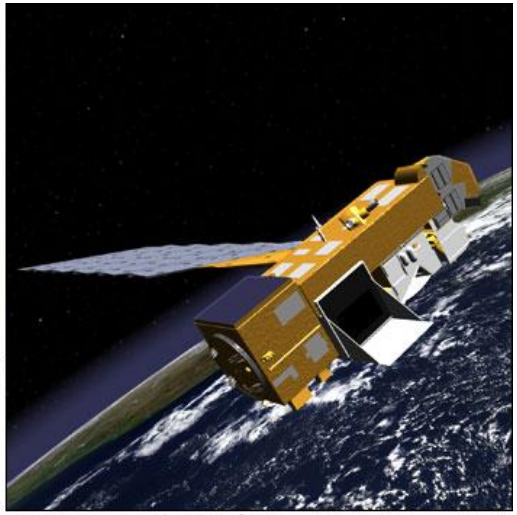
Models: • ***Chemistry-climate models*** are climate models with atmospheric composition (gases, aerosols) “on top”.

• They have advanced a lot in the last 2-3 decades, but they can improve even more.

Satellites: ***Observations of atmospheric constituents*** have produced a wealth of data (e.g. NASA A-Train), especially in the last decade.

Discover supercomputer

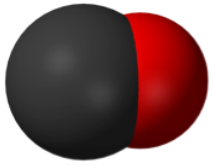
Boeing Delta II Rocket



Artist's rendering of Aura in Orbit

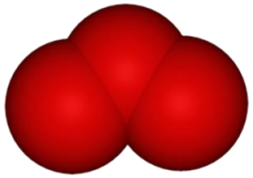
Aura satellite

Here we study CO and O_3: why?



CO

- Pollutant (primary) that can be very toxic.
- Major O_3 precursor (along with NO_x, CH_4 and VOCs).
- Affects tropospheric oxidation and climate indirectly (through its effects on OH and O_3).



O_3

- Pollutant (secondary) of major importance (toxic to humans and vegetation).
- 3rd most significant greenhouse gas.
- Affects tropospheric oxidation directly and indirectly (ozone photolysis is the major source of OH).

Also..

➔ O_3 and CO have lifetimes that are long enough for them to travel long distances but not long enough for them to be well mixed.

➔ Their chemistries are complex and interdependent.

➔ Explaining and predicting the variability of O_3 and CO still remains a challenge.

➔ Satellite observations available in conjunction with global models can help address these challenges.

➔ We don't just aim to compare modeled vs observed concentrations, but also to examine processes by performing correlation analysis and sensitivity studies.

What determines CO concentrations

Sources	
Oxidation of CH_4	
Oxidation of Isoprene	
Oxidation of Terpene	
Oxidation of industrial NMHC	
Oxidation of biomass NMHC	
Oxidation of Acetone	
Sub-total *in situ* oxidation	**881**
Vegetation	
Oceans	
Biomass burning[c]	
Fossil & domestic fuel	
Sub-total direct emissions	**1219**
Total sources	**2100**
Sinks	
Surface deposition	190
OH reaction	1920

VOCs

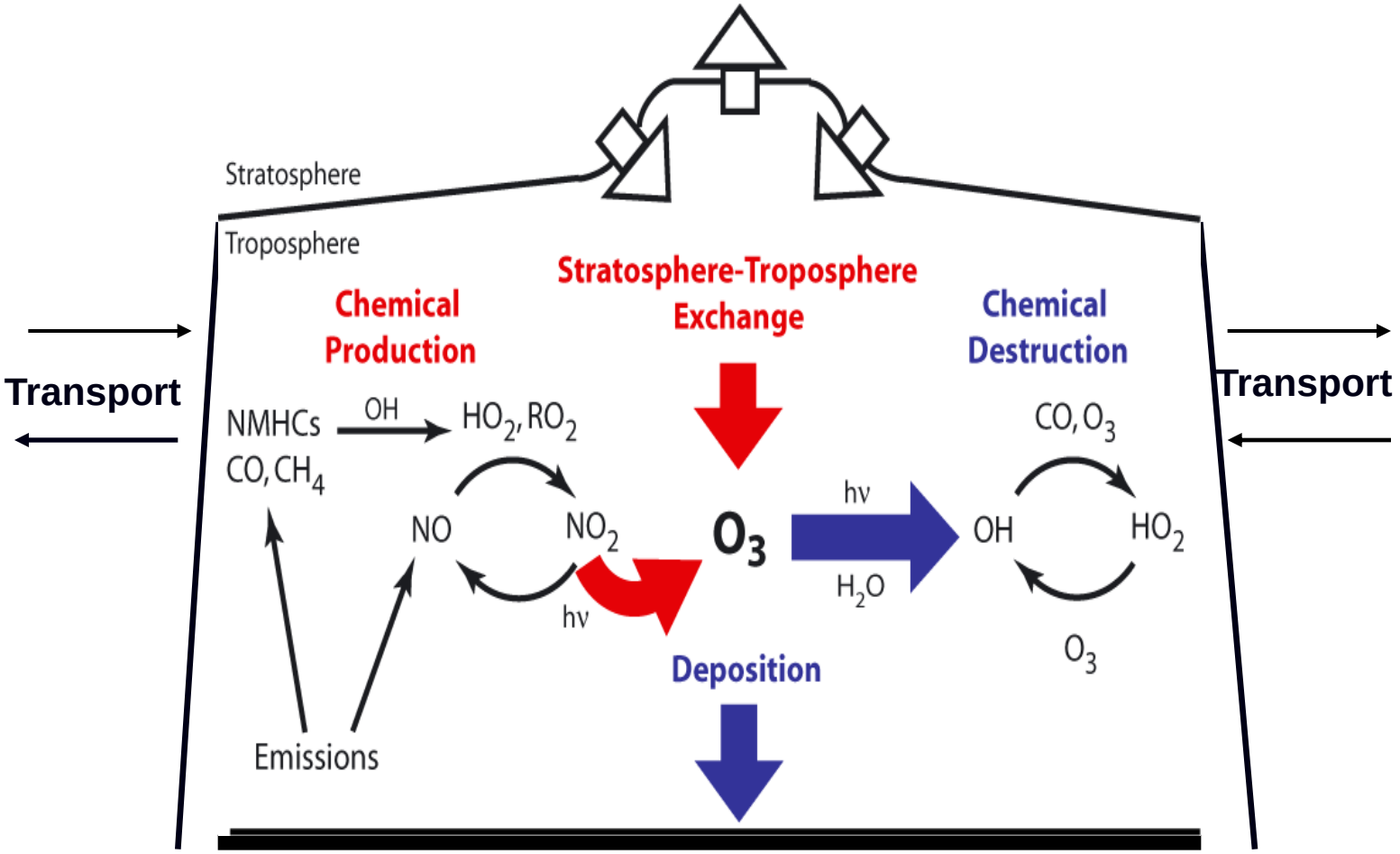
The largest oxidation source and one of the largest sources in general.

Biomass and fossil/domestic fuel are similar in size to each other and to the CH4 oxidation source.

$CO + OH \rightarrow CO_2 + H$ (oxidation)

Source: IPCC TAR.

O_3 Budget: The overall picture



Need to understand and quantify all the terms of the budget.

Results: Examining the correlation between O_3 and CO in the troposphere

(see Voulgarakis et al. [2011, ACPD])

Why study such a thing?

Two reasons:

1)Scientific motivation:

- O_3 and CO are important and complex!
- Studies have looked at their correlation using surface/aircraft measurements (e.g. *Chin et al.* [1994], *Collins et al.* [1996], *Parrish et al.* [1998], *Andrae et al.*, [2004] etc).
- But not on large geographical scales.
- They state that the O3-CO correlation shows whether a model "captures ozone well for the right reasons".
- They generally assumed that positive correlations reflect a net O_3 producing region.

Why study such a thing (continued)?

2) Data availability:

• It is the first time that simultaneous and collocated O_3 and CO measurements exist with global coverage and vertical resolution in the troposphere.

• First attempt by *Zhang et al.* [2006]: used 1 month's TES and model data.

• Here: we use data from 4-years (2005-08), involve different models and perform sensitivity runs to examine the role of emissions.

• Our approach can enhance our understanding of related processes (chemical production, transport) and contribute to model evaluation.

TES observations

- We use data from the Tropospheric Emission Spectrometer (TES) [*Beer*, 2006], a high spectral resolution Fourier-Transform IR emission spectrometer aboard the sun-synchronous EOS Aura satellite (NASA).
- The equator crossing time is at 13:45 local time.
- The retrieval uses measured radiances to provide logarithms of concentrations using the optimal estimation method.
- We use the TES Version 4 data.
- More details: http://tes.jpl.nasa.gov/

Models

- G-PUCCINI (GISS model for Physical Understanding of Composition-Climate INteractions and Impacts); See *Shindell and Faluvegi* [2010]

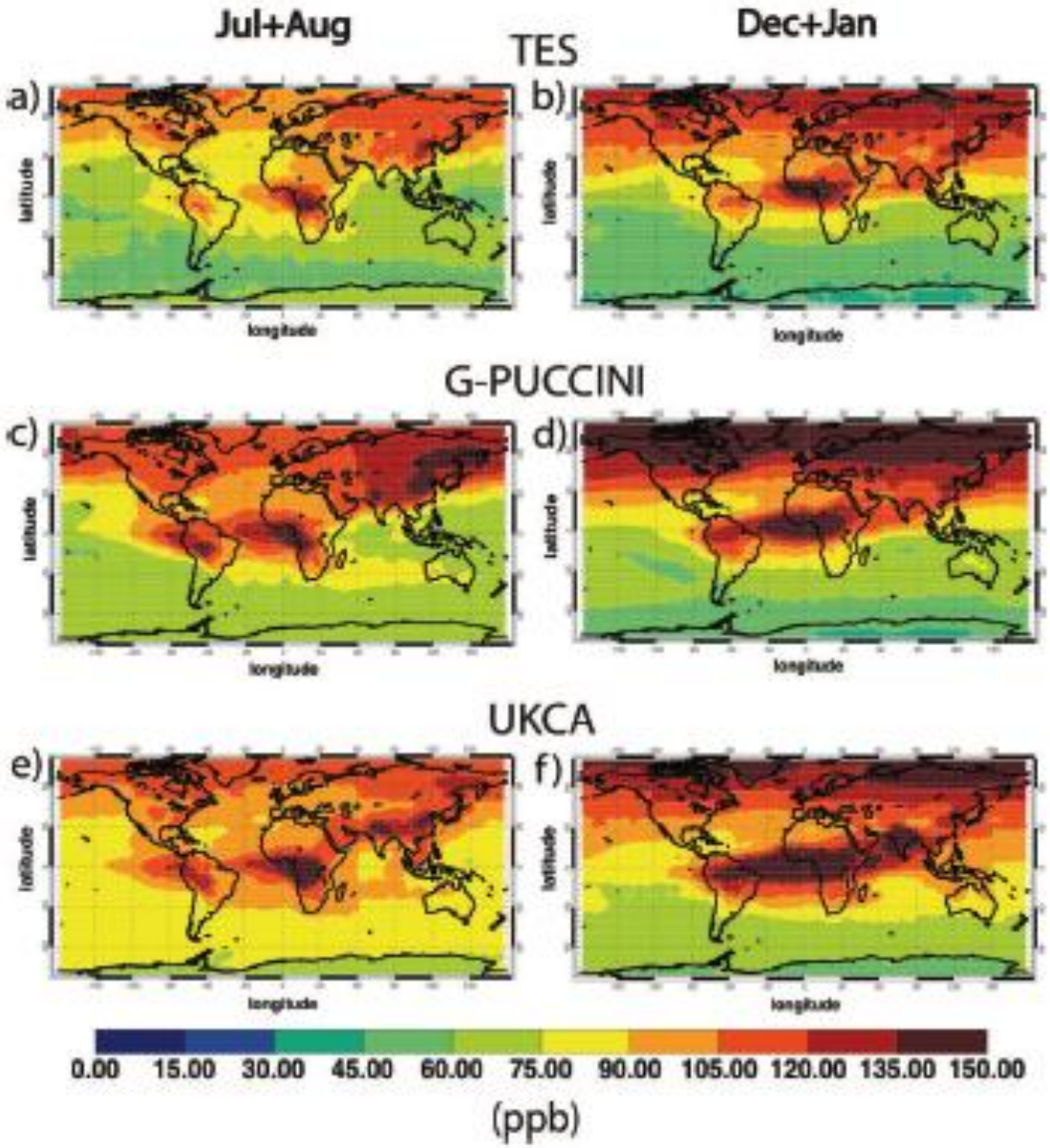
Here: 2° x2.5° resolution; 40 vertical layers; nudged winds (NCEP)
Emissions: AR5 anthropogenic; year-to-year biomass burning (GFED); interactive biogenic (isoprene only) and lightning; CH4 fixed.

- UKCA: (UK Chemistry Aerosols Model); See *Telford et al.* [2010]

Here: 3.75° x2.5° resolution; 60 vertical layers; nudged meteorology (ECMWF)
Emissions: AR5 anthropogenic and biomass burning; interactive biogenic (isoprene only) and lightning; CH_4 fixed.

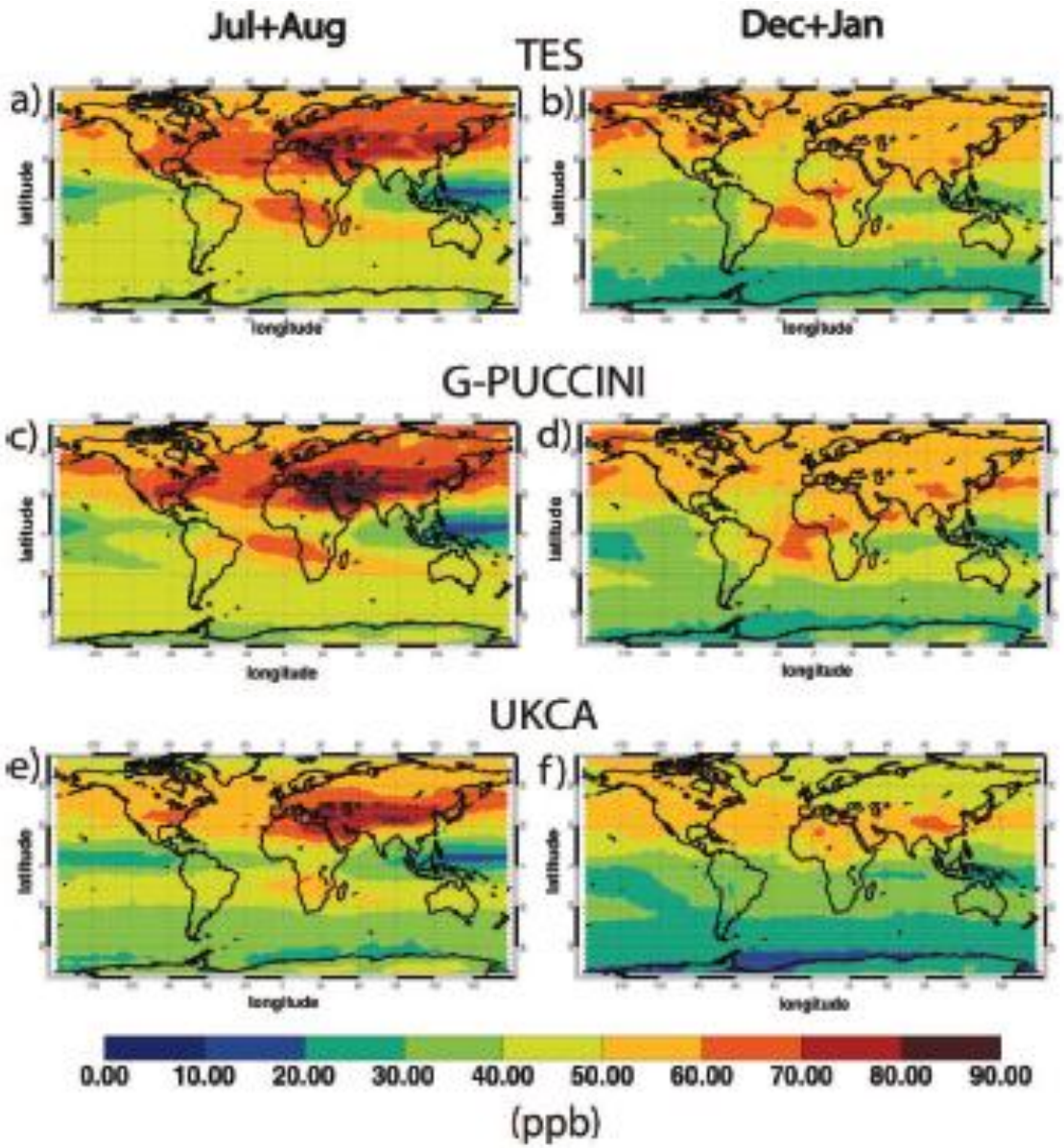
We sampled data from the models' output according to the observational time and location and have used the TES averaging kernels to process them.

Average 2005-08 CO concentration for 800-400 hPa



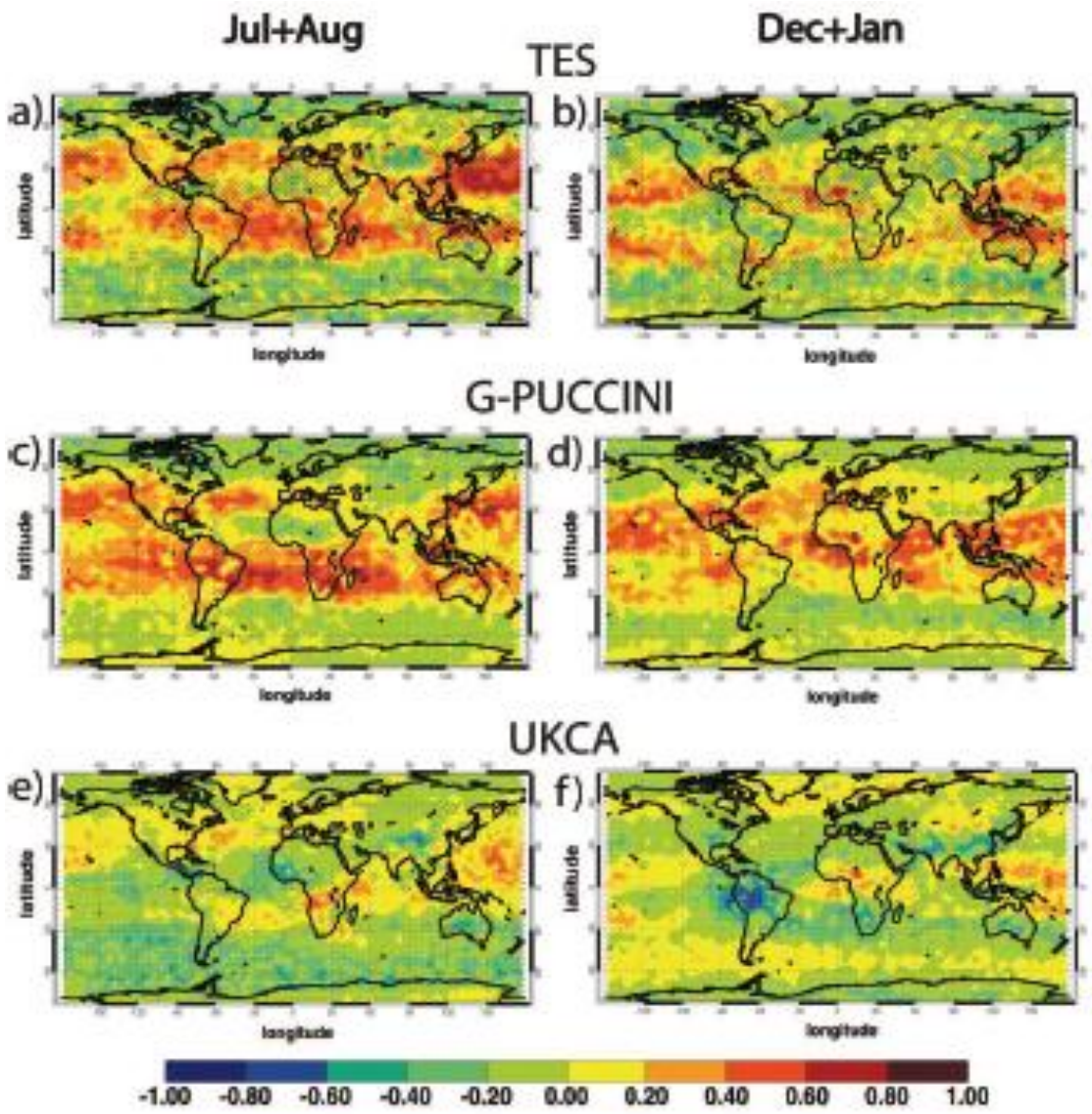
- Clearly higher CO in the winter.
- The geographical patterns are captured fairly well by both models.
- Both models show higher CO concentrations than observed, for most regions and both seasons.

Average 2005-08 O_3 concentration for 800-400 hPa



- Clearly higher O_3 in the summer.
- G-PUCCINI captures the geographical patterns and the levels well.
- UKCA captures the geographical patterns well, with somewhat lower concentrations than TES and G-PUCCINI.

O3-CO correlation (800-400 hPa average) (used 2005-08 daily data)



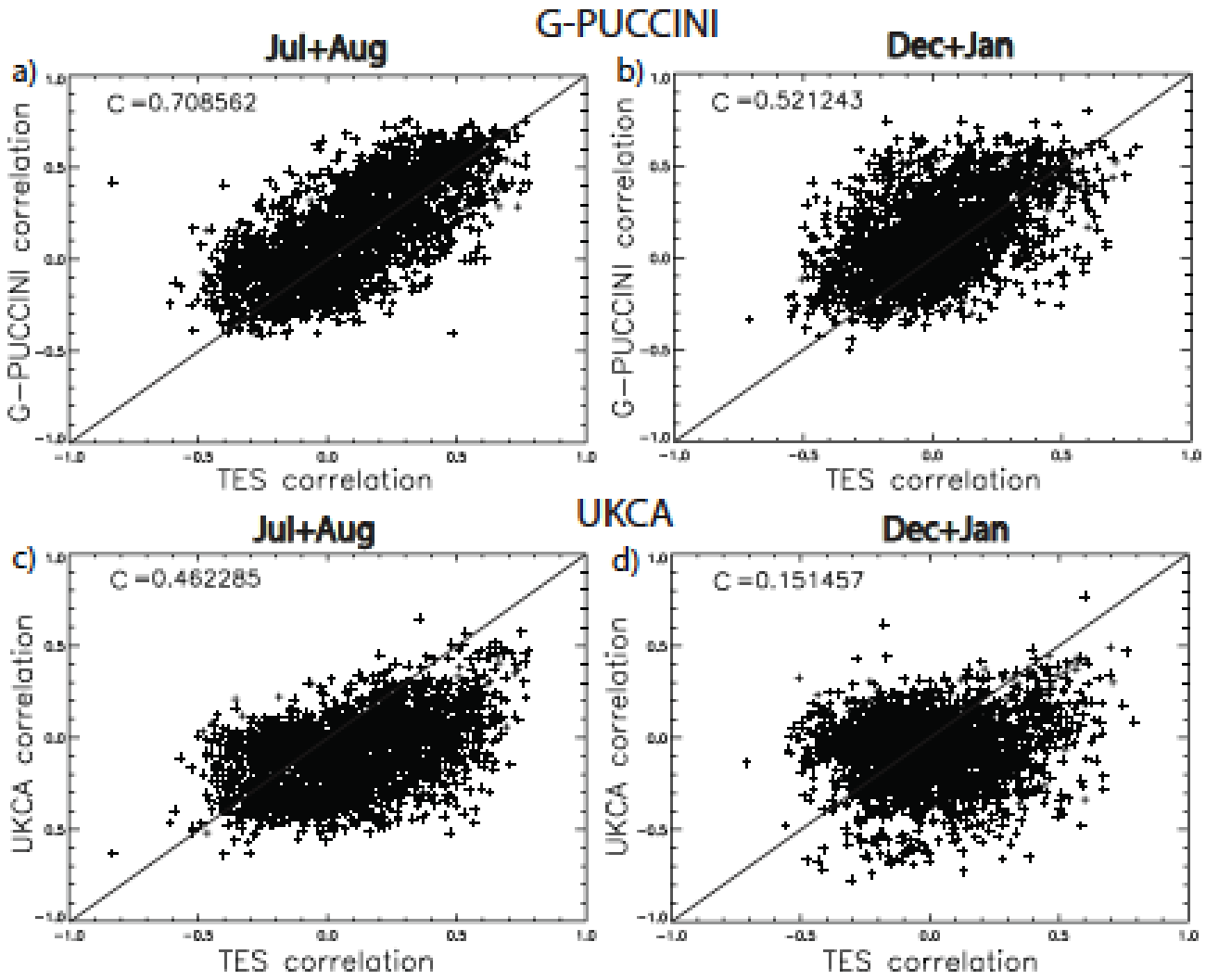
- In TES data: positive correlations in most of the Pacific, central northern Atlantic, much of the Indian Ocean, central Africa. Negative correlations in much of the northern hemisphere (excluding the oceans) and in part of the Southern Ocean.

- Many of these features are very similar in the G-PUCCINI maps.

- Also, some of these features do not change between the two seasons.

- The UKCA results are much different, although the Pacific and the Atlantic features are visible in the summer.

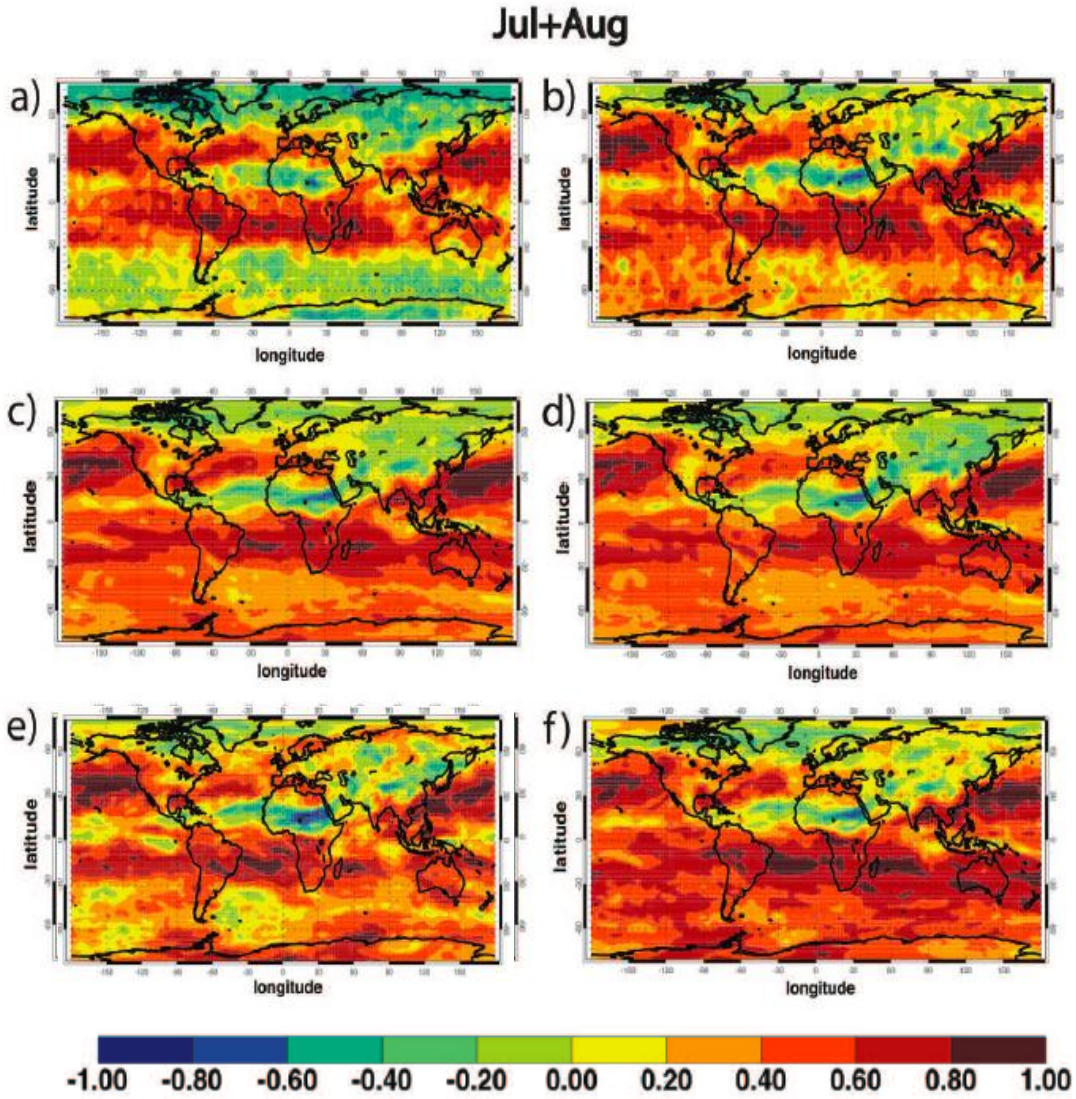
Scatter plot of modeled-observed O_3-CO correlation



Grading the models in terms of capturing the correlation

	G–PUCCINI (Jul+Aug)	UKCA (Jul+Aug)	G–PUCCINI (Dec+Jan)	UKCA (Dec+Jan)
Global	0.71	0.46	0.52	0.15
North America (120W–70W; 35N–65N)	0.70	0.33	0.32	-0.49
North Atlantic (70W–15W; 35N–65N)	0.81	0.53	0.57	-0.39
Europe (10W–35E; 35N–65N)	0.67	0.43	0.31	*-0.20*
Siberia (60E–130E; 45N–70N)	*0.15*	0.28	*0.10*	*0.16*
West Northern Pacific (130E–180W; 20N–50N)	0.72	0.64	0.58	0.24
East Northern Pacific (180W–120W; 20N–50N)	0.40	0.30	0.68	0.50
South America (80W–35W; 30S–10N)	0.23	0.27	0.18	0.40
South Atlantic (30W–0E; 30S–0N)	0.35	*0.04*	*0.22*	*-0.04*
Central Africa (10E–40E; 20S–5N)	*0.17*	*0.07*	*-0.04*	*0.23*
Indian Ocean (50E–90W; 30S–10N)	0.62	*-0.07*	-0.31	*-0.15*
West Tropical Pacific (100E–150E; 20S–20N)	0.40	0.24	*0.17*	0.28
East Tropical Pacific (130W–85W; 20S–20N)	0.41	*0.06*	0.36	0.58

Robustness of results (G-PUCCINI)



• We tested correlations in the following cases:

a) Ignoring obs. error.

b) Ignoring averaging kernels.

c) Ignoring TES sampling.

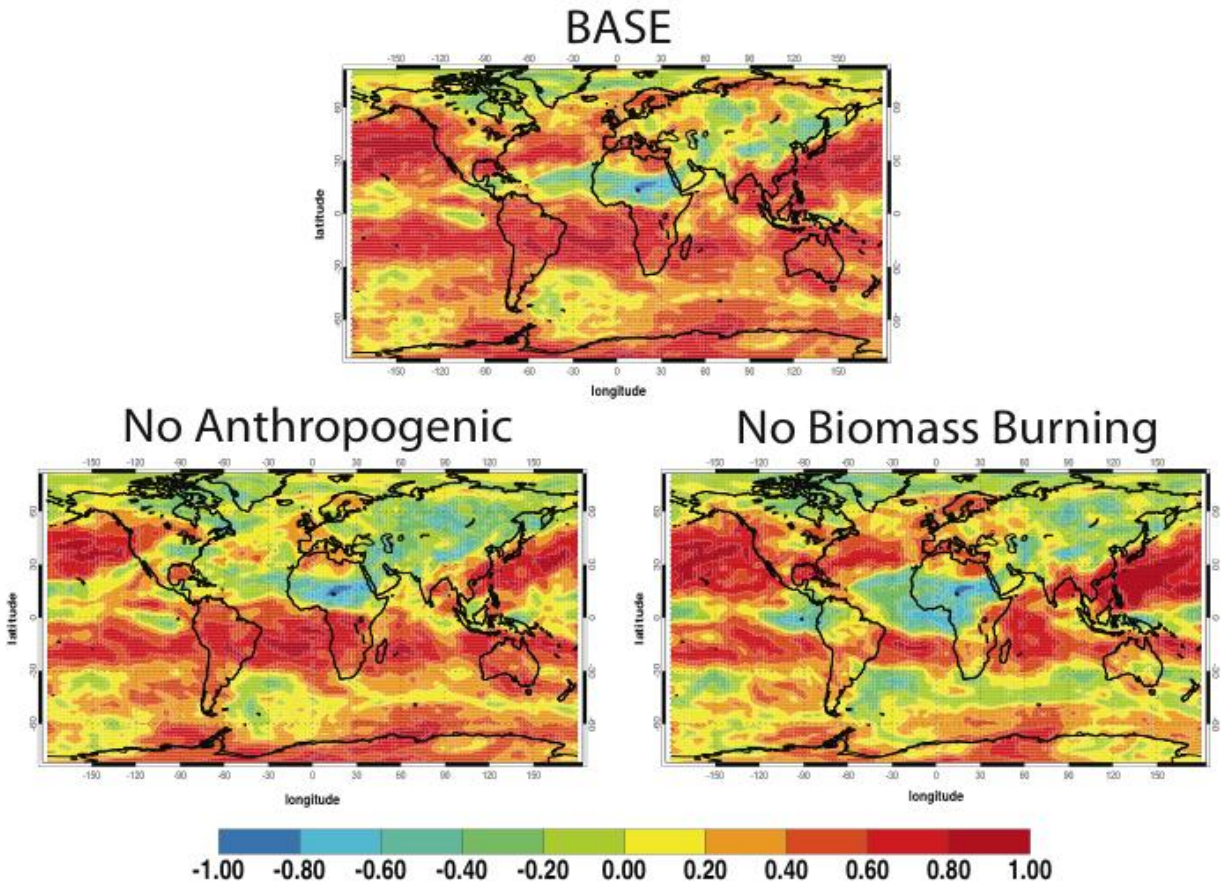
d) 562hPa instead of 800-400hPa.

e) 2006 instead of 2005-08.

f) 5-daily instead of daily averages.

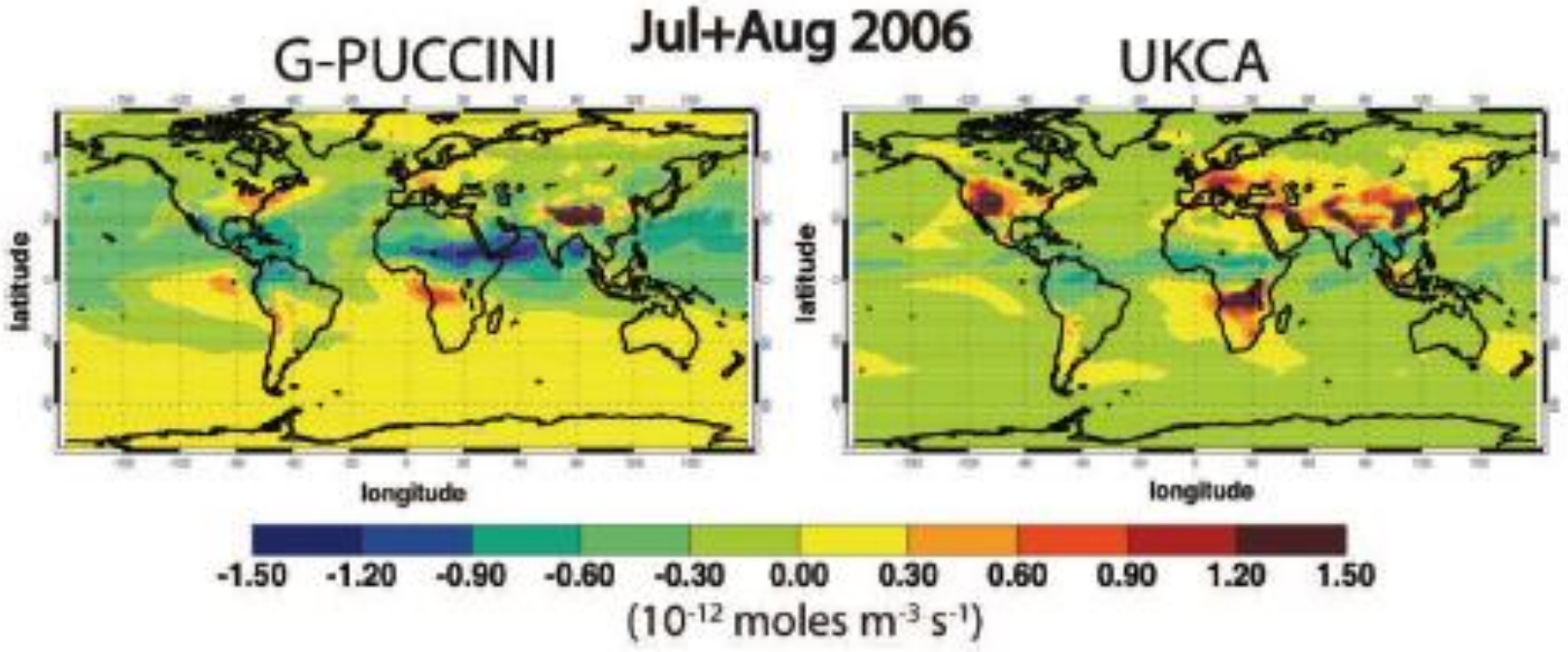
In most cases results were fairly robust.

Effect of emissions



- Biomass burning in the tropics is the only emission that can change the sign of O_3-CO correlations.
- Otherwise, correlations retain their sign, when removing individual emissions.

Exploring differences between the two models: Net O_3 chemical tendency



- The tendencies are not very different between the two models over key regions (e.g. northern Atlantic, northern Pacific).
- In fact, both models show net chemical destruction over regions with significant positive correlations.

Other potential reasons for model differences

- Emissions do not seem to be the reason based on our sensitivity analysis.
- Increased STE in the UKCA model could have been a reason.
- However, we examined the flux of O_3 through a surface right above the region of interest and actually found 20-30% smaller downward flux in the UKCA model.
- It is most likely that mixing processes (vertical and horizontal) are responsible.
- Also, photolysis is treated very differently in the two models, but its effect on O_3-CO correlations remains to be examined.

Main conclusions

- We identified regions of the globe where short-term O_3-CO correlations are positive and negative.
- In some regions, the correlations are strong, the highlight being the Northern Pacific.
- Several geographical features are fairly robust across different estimates. However, the models also have some major differences.
- We found that emissions do not necessarily drive the sign of the correlations.
- We also found that positive correlations occur even in large ozone-destroying regions, contrary to what is usually assumed.
- It is more likely that differences in O_3-CO correlations in the models are a result of differences in vertical and horizontal mixing.

Future work

- Follow-up on the O_3-CO correlation study with more extensive dynamical analysis.
- Study of the role of clouds in driving the correlation differences.
- Investigate how correlations may change in a future atmosphere.
- Evaluate more models in how well they capture O_3-CO correlations, as part of the Atmospheric Chemistry and Climate effort (ACC-MIP), in support of the IPCC AR5.
- Expand our correlation studies to use a variety of other satellite products in conjunction with the models, to explore gas-gas, gas-aerosol, gas/aerosol-process (convection, lightning, clouds etc) relationships.

Acknowledgements:

• Drew Shindell, Greg Faluvegi and Olga Pechony from the **NASA GISS/Columbia** side.

• John Pyle, Paul Telford, Peter Braesicke and Luke Abraham from the **University of Cambridge/NCAS** side.

• Kevin Bowman and Adetutu Aghedo from **JPL (Caltech)**.

• NASA ACMAP for funding.

Thank You!!

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y. 10025

CENTER FOR CLIMATE SYSTEMS RESEARCH
THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY